US Army Corps of Engineers

Chronic Beach Erosion Adjacent to Inlets and Remediation by Composite (T-Head) Groins

by Hans Hanson and Nicholas C. Kraus

PURPOSE: Beaches located directly downdrift of inlets may become isolated from sediment sources and experience chronic erosion. Because shore-protection actions taken on a beach isolated from sediment sources may not significantly disturb the downdrift beach, highly efficient sand-retention structures such as T-head and L-head groins may be considered as a remediation measure. The Coastal and Hydraulics Engineering Technical Note (CHETN) described herein gives an overview of the performance and functional design procedures for T-head and similar composite groins.

INLET PROCESSES AND DOWNDRIFT EROSION: Beaches located directly downdrift of inlets where there is a dominant direction of net longshore transport can experience persistent erosion. Recession of the shoreline can occur at a high rate, and breaching becomes a possibility at inlets on barrier islands. This situation is illustrated in Figure 1 for Shinnecock Inlet, Long Island, NY, in October 1996. The south shore of Long Island is oriented approximately east-west, and impoundment at the east jetty (right side of figure) and erosion at the west jetty indicate a net transport directed strongly to the west. In addition, the pattern of wave breaking over the ebb-tidal shoal is asymmetric, with strong skewness toward the west, also indicating net longshore transport to the west. The coast of Long Island is formed of glacial deposits, and the grain size of the predominantly sand sediment ranges between 0.2 and 0.6 mm.

Figure 2 shows inferred sediment paths at Shinnecock Inlet based upon knowledge of the morphology, waves, and currents. Sand moving from east to west can follow Path 1a (move around ebb shoal and bypassing bar to reach the attachment bar) or follow Path 1b (enter the channel and deposition basin). Material reaching the attachment bar can continue to the west (Path 2a), or be transported east (Path 2b), depending upon the direction of wave incidence and tidal current. Material on the west beach can move west or east (Path 3), and if it moves east it can enter the channel to be deposited there, or move to the flood shoal or to the ebb shoal (Path 4). Because sand bypassing along Path 1a and growth of the large attachment bar, which can act as a groin, the beach segment between the west jetty and downdrift attachment bar has become relatively isolated from adjacent sand sources. Therefore, the west beach experiences chronic erosion. Bruun (1995) discusses the near field behavior (between downdrift jetty and attachment bar) and far field behavior (further down drift from attachment bar) of longshore transport and shoreline evolution.

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14. ABSTRACT
Beaches located directly downdrift of inlets may become isolated from sediment sources and experience chronic erosion. Because shore-protection actions taken on a beach isolated from sediment sources may not significantly disturb the downdrift beach, highly efficient sand-retention structures such as T-head and L-head groins may be considered as a remediation measure. This Coastal and Hydraulics Engineering Technical Note (CHETN) gives an overview of the performance and functional design procedures for T-head and similar composite groins.

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Figure 1. Shinnecock Inlet, with waves breaking on the ebb shoal and bypassing bars (note gap in wave breaking at the location of the deposition basin, allowing wave penetration)

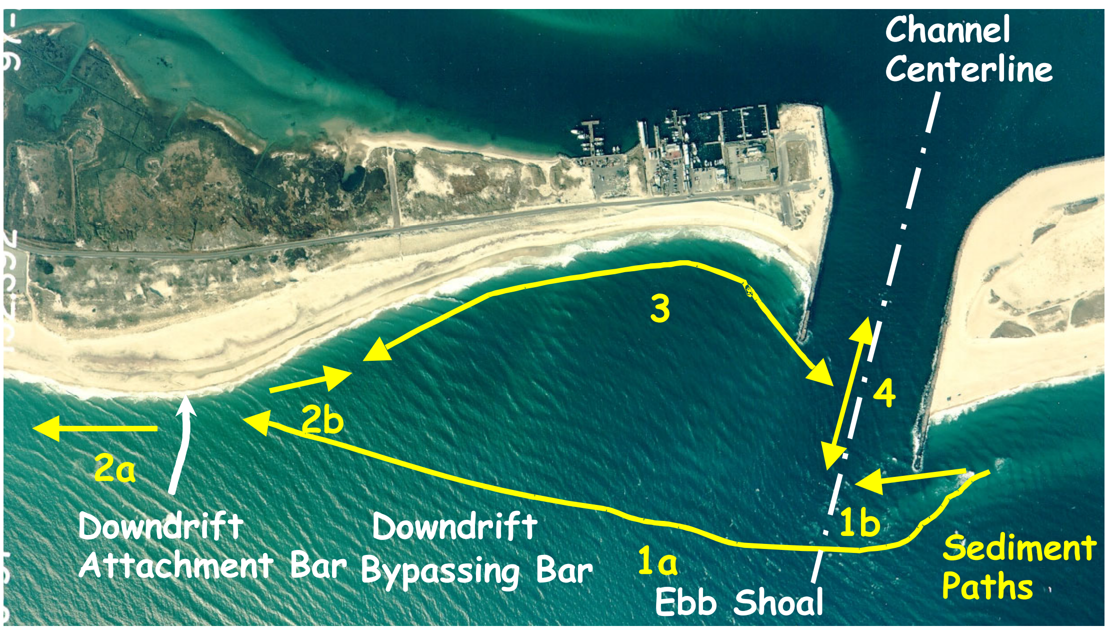

Figure 2. Interpreted sediment paths at Shinnecock Inlet channel and west beach

OVERVIEW OF GROIN FUNCTIONING:

Single Groins: Groins are one of the oldest shore-protection devices and arose from recognition that structures piercing the surf zone intercept sediment moving along the shore. Kraus, Hanson, and Blomgren (1994) review the literature and describe a numerical modeling

approach to functional design of straight groins. Four parameters were identified as having main control on the functioning of individual groins:

a. Ratio of net to gross longshore sand transport rates;

b. Ratio of depth at the groin tip to the depth of the seaward limit of the average surf zone width; and

c. Structure permeability (structure porosity and crest elevation).

d. Sediment grain size or fall speed.

For groin fields, the ratio formed as the separation distance between groins divided by the effective or design length (distance between the seaward tip of groin to the position of the design shoreline) is another governing parameter.

Composite Groins: At beaches located directly downdrift of jetties and at other erosional hot spots (project areas with high rates of erosion or shoreline recession than at neighboring beaches (Kraus and Galgano 2001), beach nourishment without additional protection is not typically economically feasible, and simple groins may not be adequate. Composite groins have shore-parallel segments added to a straight groin, called the stem. Thus, groins with composite plan shapes such as spur, inclined, angular, Z-shape, L-head, and T-head, groins, as shown in Figure 3 have been constructed with the aim of achieving a more stable dynamic-equilibrium beach plan shape (Bruun 1952; Barceló 1970; Bodge 1998). Since the early 1990s, new strategies have been developed to predict the equilibrium plan shape (Silvester and Hsu 1993; Bodge 1998; González and Medina 1999; Moreno and Kraus 1999), and these can aid in the functional design of composite groins.

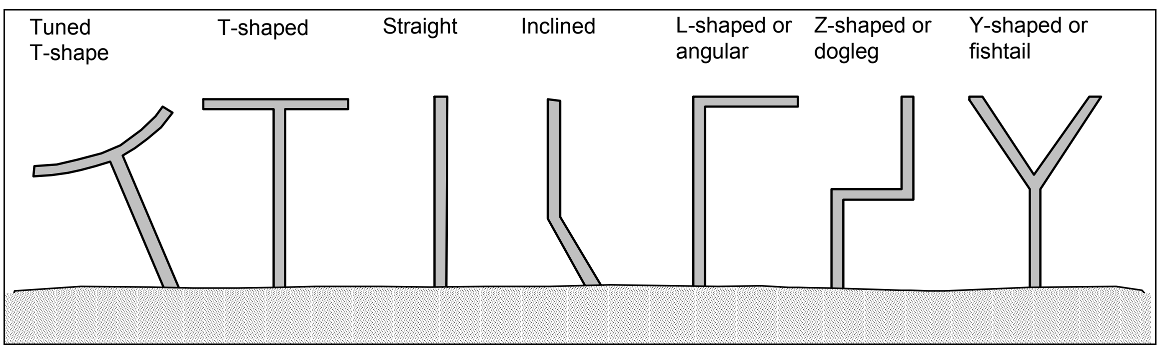

Figure 3. Examples of plan shapes of different composite groins

Composite groins are considered more efficient than straight groins in holding the local shoreline position. Composite groins reduce or laterally redirect the rip current that forms at the updrift side of the groin, thereby reducing offshore losses and sand bypassing. The shore-parallel segments shelter the leeward local beach, promoting accumulation of sediment. Accretion behind the structure also reduces the wave height that, in turn, will decrease the wave steepness. As a consequence, with approach to the stem, the waves will tend to transform from more erosional to more accretionary (Bruun 1952). Diffraction at the tip of a headland is a decisive process controlling shoreline shape. The tombolo or seaward-oriented portion of the shoreline at a composite groin evolves toward a shoreline plan shape approximately parallel to the incident

waves that have transformed by diffraction and refraction, reducing longshore transport at the groin. This dynamically stable curved orientation of the shoreline is analogous to that of a headland bay (Krumbein 1944; Silvester 1960, 1970, 1976; Yasso 1965), producing a characteristic spiral and similarly shaped crenulate beach.

In summary, reduction of the rip current; wave sheltering by the shore-parallel segment of a composite groin; reduction in wave steepness in the sheltered regions; and inducing of significant diffraction distinguish the functioning of composite groins from straight groins.

In the United States, T-head and similar high-efficiency composite structures have seen limited application because of concern for and regulatory protection of the downdrift beaches. Instead, placement of fill[1] on the beach or in the nearshore is the preferred means of addressing erosion and sediment loss. The fill adds material to the system and typically benefits the downdrift beaches[2]. Sand-retention structures such as terminal groins are sometimes constructed to extend the life of material placed on the beach. These structures may be designed to allow a certain amount of material to bypass them, as well as be deployed in combination with feeder beaches.

Selected Experiences with Composite Groins: Matthews (1934) reported that in situations with limited supply of sediment or if the beach is subject to shore-normal storm waves, the groins should be supplemented with a T-head. He cautioned that there was limited experience with the performance of these structures.

Frech (1949) discussed the performance of T-head groins built at Asbury Park, NJ. The study concluded the T-head groins created not only sand accumulations on the updrift sides, but they also produced considerable accumulation on the downdrift (wave-sheltered) sides, in comparison to straight groins that did not hold as much sand. Also, Frech observed that the T-head groins had effectively prevented the bluff behind them from eroding.

Ishihara and Sawaragi (1964) investigated the stability of beaches protected by T-head groins. They found that the T-head structures stabilized the local beaches effectively. In particular, they noted that the shape of the beach between the groins was almost independent of changes in the direction of littoral drift. As a conclusion they recommend these structures particularly where the direction of littoral drift "furiously changes."

Sato and Tanaka (1974) evaluated different combinations of groins and offshore breakwaters in the laboratory and the field to find an appropriate solution to erosion problems at Suma Beach west of Kobe, Japan. The structures were designed to retain a beach fill. In general, the outcome of the field and model tests agreed well and indicated that offshore breakwaters in combination with straight groins provided the best retaining capability of the filled sand. Also, T-groins were found to offer better protection than a combination of regular groins and submerged breakwaters.

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[1] In U.S. Army Corps of Engineers practice, the term "beach fill" refers to material placed as part of an authorized hurricane and storm-damage reduction project, and not to disposal of dredged material as part of navigational channel maintenance. In this note, the term "beach fill" covers any type of placement of material on the beach, irrespective of authorization or sponsor.

[2] Occasionally, downdrift movement of material is not desirable for environmental reasons, such as the potential to cover hard bottom that may be considered a habitat resource.

Berenguer and Enríquez (1988) examined data from 34 pocket beaches, typically comprised of detached breakwaters with tombolos rather than T-head groins. Based on this work, empirical relationships between key parameters were derived. Examples of such relationships are (area of water inside structures)/(total area inside structures) and (maximum setback distance from the structure tip to the shore)/(gap width).

Olsen and Bodge (1991) discussed placement of "tuned" T-head groins as an effective means of controlling the direction of longshore transport and preventing offshore losses of sediment. Through a number of practical applications, they developed a methodology for obtaining stable beach fills with placement of T-head groins.

Hardaway and Gunn (1999) reported on headland breakwater protection systems in Chesapeake Bay. The breakwaters produced tombolos. They investigated a functional design relationship involving a ratio as the maximum setback distance from the structure tip to the shore divided by the gap width. However, designs for bay hydrodynamic conditions, with predominance of wind waves and influences of river flow and tidal currents, may not be directly applicable to the open coast.

Characteristic Shoreline Shape at T-Head Groins: At both ends of a T-head groin, waves progress by undergoing diffraction and refraction (Figure 4), producing an equilibrium embayment on each side of the central stem.

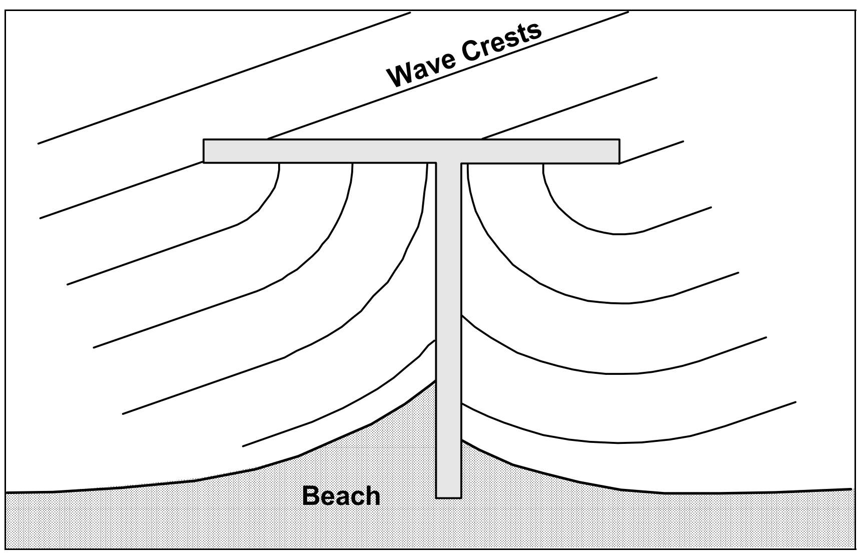

Figure 4. Schematic of wave propagation at a T-head groin

Shoreline response to a T-head groin is similar to that of a detached breakwater (Pope and Dean 1986). The main difference is that the beach plan shape behind the T-head structure is controlled by waves arriving at one side of the structure, with no opposing waves and currents possible. As a consequence, the salient behind a detached breakwater is expected to grow more slowly than a salient behind a T-head groin, other conditions being equal (Figure 5). The shoreline grows until a salient or tombolo is fully formed, after which further functioning of the two structures should be the same. Thus, shoreline response to a T-head groin is more analogous to a headland than to a detached breakwater.

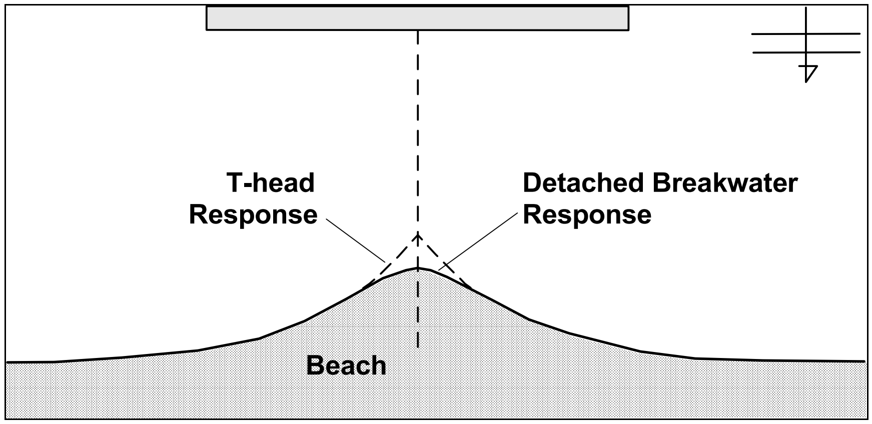

Figure 5. Schematic of shoreline response to T-head groin and detached breakwater, respectively

One disadvantage of the T-head groin as compared to the detached breakwater is that downdrift reduction in transport is potentially greater (Hanson and Kraus 2000). In many projects, development of a tombolo inside of a detached breakwater is not a design goal. By allowing open water between the breakwater and beach behind it, sand can potentially move through the system to downdrift beaches. With the groin blocking transport, movement of material to downdrift beaches is decreased.

HEADLAND BAY PLAN SHAPES: An open sandy beach placed in the lee of a composite groin or headland-type structure will gradually develop a bay of a characteristic curved plan shape (Figure 2) under wave-induced transport. These shapes have been termed crenulate bays, static equilibrium bays, and spiral beaches and have been described mathematically as a log spiral (Krumbein 1944; Yasso 1965; Silvester 1976), parabolic shape (Hsu, Silvester, and Xia 1987; Silvester and Hsu 1993), or hyperbolic tangent shape (Moreno and Kraus 1999). Here, we discuss the parabolic and hyperbolic shapes.

Parabolic Shape: The parabolic shape is given by

$$\frac{R}{R_0} = C_0 + C_1\left(\frac{\beta}{\theta}\right) + C_2\left(\frac{\beta}{\theta}\right)^2, \qquad \theta \geq \beta \tag{1}$$

$$\frac{R}{R_0} = \frac{\sin\beta}{\sin\theta}, \qquad \theta < \beta \tag{2}$$

where R = radius of the curve at an angle θ, R_0 = radius to the control point (transition point between the curved part of the bay and the straight part that is parallel to the incoming waves), β = angle defining the bay shape, θ = angle between incoming wave crests and radius line R, and C_0, C_1, and C_2 = coefficients determined as functions of β. The resultant shape appears as in Figure 6.

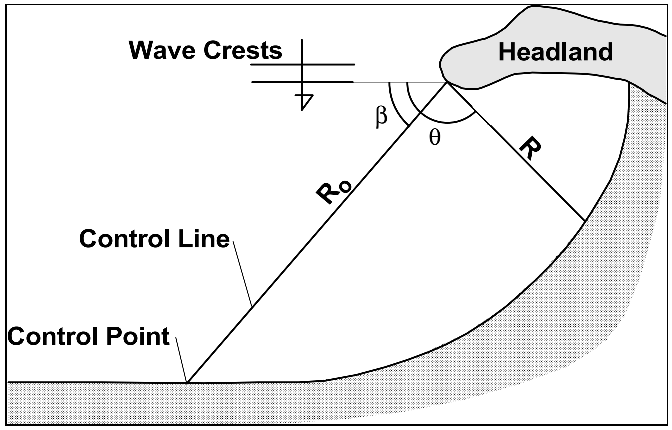

Figure 6. Definition sketch of equilibrium bay plan shape

The *C*-coefficients are given in Table 1 and were derived from fitting to measured shorelines (Hsu and Evans 1989).

Table 1
Coefficients for Parabolic Shoreline, Equation 1, from (Hsu and Evans 1989)

β (deg)	C_o	C_1	C_2
10	0.036	1.011	-0.047
15	0.050	0.998	-0.049
20	0.055	1.029	-0.088
25	0.054	1.083	-0.142
30	0.045	1.146	-0.194
35	0.029	1.220	-0.253
40	0.000	1.326	-0.332
45	-0.039	1.446	-0.412
50	-0.088	1.588	-0.507
55	-0.151	1.756	-0.611
60	-0.227	1.930	-0.706
65	-0.315	2.113	-0.800
70	-0.409	2.284	-0.873
75	-0.505	2.422	-0.909
80	-0.600	2.520	-0.906

González and Medina (1999, 2000) proposed a modification of the parabolic-function approach of Hsu and Evans (1989). Based on an analytic model of minimal longshore current in combination with observations of shoreline shapes, a procedure for locating the downdrift control point (Figure 7) was developed. The angle β between the wave crest corresponding to the direction of mean energy flux and the control line is given as (in deg):

$$\beta = 90 - \arctan\left[\left(1.286 + 2.268\frac{Y}{L}\right)^{0.5}\frac{L}{Y}\right] \tag{3}$$

where Y = orthogonal distance between the diffraction point and the control point, and L = average wavelength between the groin tip and control point, corresponding to the peak period associated with H_{s12} = significant wave height exceeded 12 hr/year. From this point, the rest of the bay shape may be determined by means of the Hsu and Evans (1989) formulas (Equations 1 and 2).

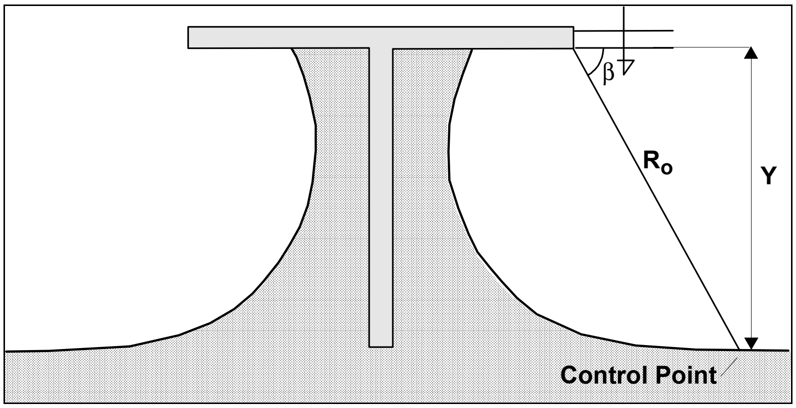

Figure 7. Schematic tombolo shape inside of T-head groin

The method is shown to be applicable to natural as well as artificially constructed beaches and, similar to the method of Hsu and Evans (1989), it is assumed that the bay shape is controlled by one diffracting point. The method includes cases with T-head groins or with detached breakwaters with tombolos. For situations with a salient behind a detached breakwater, a modified approach is recommended. The González and Medina (1999, 2000) method was demonstrated to work for situations with one end of the bay open. Guidance was not given for prediction of the shoreline response to a field of T-head groins but appears to be adaptable.

Hyperbolic Shape: A hyperbolic function for describing headland shapes was introduced by Moreno and Kraus (1999) and is defined in an orthogonal coordinate system relative to the shoreline and structure as

$$y = \pm a \tanh^m(bx) \tag{4}$$

where y = distance across shore, x = distance alongshore, and a = distance along the y-axis between diffracting tip and shoreline beyond influence of the headland (similar to the location of the control point in the parabolic shape), b = empirical scaling factor, and m = empirical coefficient. Fittings to 46 beaches in Spain and North America with shoreline shapes formed at natural headlands and at engineering structures gave:

$$ab \cong 1.2, \qquad m \cong 0.5 \tag{5}$$

In application, the origin, $(x, y) = (0, 0)$ is placed where the shoreline is expected to start. For T-head groins, the origin should be placed where the seaward portion of the salient is expected to end, with the x-axis parallel to the wave crests (of the prevalent waves). The value of the parameter a is specified based on site-specific fitting or on a design criterion, such as Equation 3.

DESIGN METHODS FOR T-HEAD GROIN BEACH PROTECTION: Based on experience in numerous projects, Bodge (1998) describes a design protocol for tuning T-head groins for stabilization of beaches. Tuning refers to an iterative functional design procedure for optimum protection or beach-fill performance. The basic assumptions in this process (Figure 8) are that the shoreline will be parallel to a line connecting the two T-heads and that it is located a distance $G/3$ from this line, where G = gap width or distance between adjacent T-heads. In this method, it is the gap and shoreline behind it that is aligned to the crests of the predominant waves, and not the T-heads. This procedure produces a preliminary mean low water (mlw) shoreline to determine the lengths and number of structures needed to ensure that the mlw shoreline reaches the T-heads. For final design, a composite shoreline is made from the simple $G/3$ shoreline and the parabolic shoreline corresponding to Equation 1. From the mlw shoreline, the location of any other beach contour may be predicted by an upslope transition based on the existing profile slope of a nearby beach.

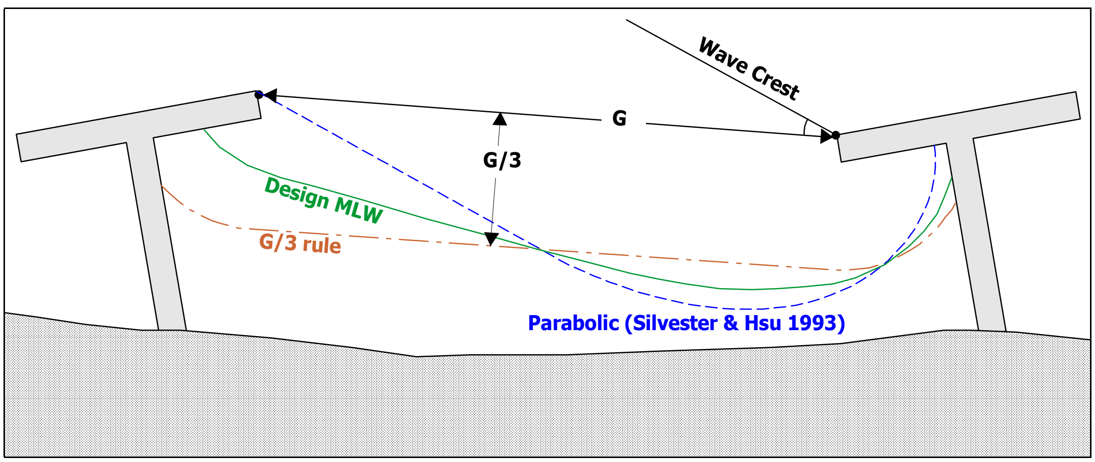

Figure 8. Bodge method prediction of mlw shoreline in T-head groin compartments

Hardaway and Gunn (1999) discuss general design procedures and performance of three sites protected by headland breakwater systems (regular detached breakwaters with tombolos but not T-head groins) in Chesapeake Bay. A methodology is not given. The data in their study suggest that the stable shoreline between two headlands is located about $2G/3$ behind from the line connecting the headlands. This distance is twice that entering the method of Bodge (1998). Several explanations are possible for the difference. Although not explicitly stated, the shoreline of the Hardaway and Gunn (1999) procedure is likely referenced to mean sea level whereas the Bodge (1998) method refers to mlw. Also, Chesapeake Bay has shorter period waves than most coasts (less refraction and diffraction than longer period waves). The amount to which a project area is prefilled is a controlling factor. Typically, Corps projects fill groin compartments completely at initial construction to serve as a feeder beach for the downdrift shore.

Movable-bed physical models provide a means of refining empirically based designs, and numerical models such as GENESIS (Hanson and Kraus 1989) are being enhanced to better simulate beach response to composite structures (Hanson and Kraus 2000). GENESIS can describe wave transmission at such structures.

Construction of composite structures can proceed modularly to allow flexibility for tuning the system. For example, based on observed beach response, structures can be modified, added, or removed. The performance of trial designs can be evaluated by first placing sediment-filled geotextile units, which are relatively easily moved or demobilized as compared to rubble-mound structures. Monitoring of the beach downdrift of the project assures proper amounts of material are bypassed or supplied directly and that the composite system does not bring unanticipated consequences.

EXAMPLES

Example 1: As an illustration of the different methods for estimating the equilibrium plan shape of a proposed T-head groin system, the simple hypothetical configuration in Figure 9 is considered. This alternative consists of two T-head groins to be built along an open sandy coast. Initial design calls for the groins to extend about 40 m (135 ft) from the existing shoreline, and the distance between the adjacent diffracting T-head tips is 105 m (344 ft). The groin compartment will be filled upon completion of the structures and a feeder beach constructed to provide a certain amount of material to the downdrift beach. The prevailing incident waves arrive at an angle of 29 deg to the line connecting the diffracting tips of the structures. The design wave period is 6 sec, giving a deepwater wavelength of L_0 = 56 m (184 ft). With a depth at the diffracting tips of 0.5 m (1.6 ft), the wavelength L at the tips is 13.5 m (44.3 ft).

For the parabolic shape (Silvester and Hsu 1993) the location of the control point is determined by means of Equation 3, with the orthogonal distance Y = 43 m (142 ft), yielding β = 48 deg relative to the incident wave crests. This determines the R_0-line as indicated in Figure 9. This line then denotes the transition between the curved and the straight sections of the equilibrium shoreline, where the straight section is parallel to the waves. In addition, it is assumed that the shoreline passes through the down-coast diffracting point. With C_0, C_1, and C_2 given in Table 1, the parabolic shoreline is drawn.

In the Bodge method (Bodge 1998), the G/3 line is drawn 105/3 = 35 m (114.8 ft) behind the line connecting the two diffracting points. Closer to the structures, the G/3 line is drawn as a circle with a 35-m radius. The composite mlw design line is then placed half way between the parabolic line and the G/3 line, in Figure 9 denoted as "Design mlw."

The hyperbolic shape (Moreno and Kraus 1999) can be generated similarly to the parabolic shape, aligning the downdrift distant shoreline with the direction of the incident waves at the gap. For this example, the origin was placed a distance of one-third the stem length from the intersection of the stem and the T, and the orthogonal distance to this origin was a = 42 m (138 ft). By Equation 5, b = 1.2/a, and m =0.5. If there are other T-head groins at the site, the origin can be located where the major portion of the salients end with respect to the T; if no information is available, at the present time the one-third distance is recommended.

Figure 9 indicates that all methods give comparable results, in particular at the updrift section of the embayment. On the downdrift end, the shorelines for the parabolic and hyperbolic methods were set to connect with the diffracting tip. This is a convenient approach, but not a necessary one.

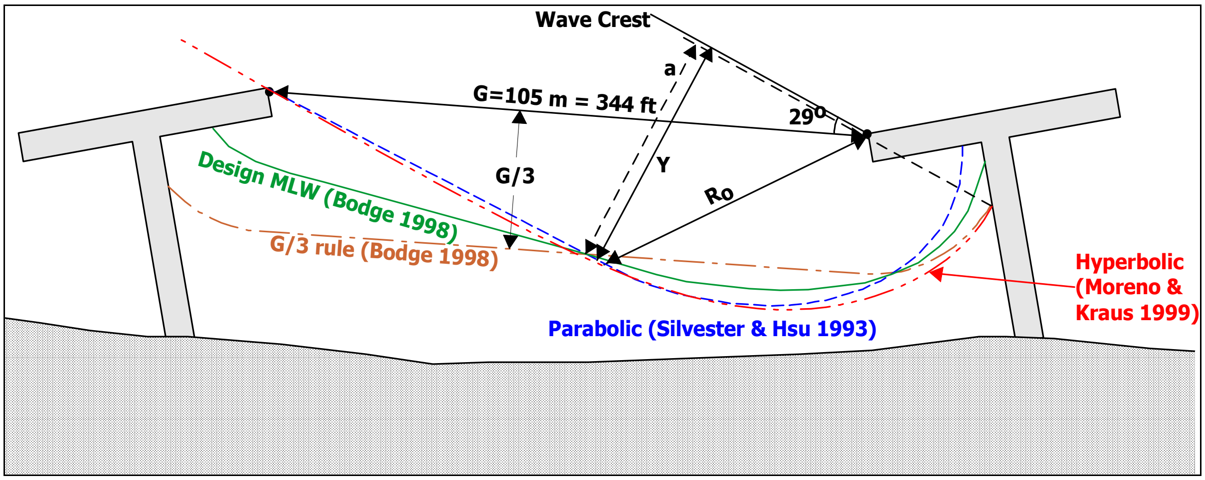

Figure 9. Comparison between Bodge, parabolic, and hyperbolic plan-shape methods

Example 2: Figure 10 shows a Federally authorized T-groin project located in southern Palm Beach County, FL. The downdrift beach between the jetty and attachment bar is isolated from major sediment inputs from the lateral sides. The following discussion is summarized from Creed and Olsen (1999). The reader is directed to that paper for more information.

Olsen Associates, Inc., designed the Federally funded Ocean Ridge Shore Protection Project by means of the methodology as described by Bodge (1998) (also discussed in Example 1). The project was completed in April 1998 and consists of eight rubble-mound T-head groins and placement of 610,000 cu m (800,000 cu yd) of sand fill along 2,350 m (7,700 ft) of shoreline. The project is located directly south of South Lake Worth Inlet, in a chronically eroding region of the coast. Mechanical bypassing of sand around the inlet averages approximately 50,200 cu m/year (65,700 cu yd/year). Preproject (1975-1993) shoreline-change rates within this region range from slight accretion at the bypassing discharge location (0.2 m/year or 0.5 ft/year) to significant recession (1.2 m/year or 4 ft/year)) approximately 1,830 m (6,000 ft) south of the south jetty.

The purpose of the project was to mitigate long-term chronic shoreline erosion and offset a continuing sediment transport deficit caused by South Lake Worth Inlet, estimated to be 29,300 cu m/year (38,400 cu yd/year). Prior to detailed design, companion studies included:

a. Development of an inlet sediment budget;

b. Analysis of historical rates of shoreline change;

c. Modeling of wave refraction and diffraction;

d. Modeling of shoreline change, and

e. Analysis of existing natural (hard-bottom outcroppings) and anthropogenic factors (existing seawalls and groins) that might influence project design.

The eight T-head rubble-mound groins are spaced approximately 73 m (240 ft) apart along 550 m (1,800 ft) of shoreline. The T-head design configuration was specified to maintain a minimum recreational design beach and to reduce the potential for generation of rip currents (and associated sediment losses) along the groin stems during storms. The dimensions and orientations of the T-head structures vary to account for the higher erosional trends near the northern part of the region. To minimize potential for loss of beach directly downdrift of the project, a sand fill transition was included. It was recommended that future sand bypassed quantities be discharged primarily within the transition zone.

Figure 10. The Ocean Ridge Shore Protection Project under construction, March 1998 (photograph courtesy Olsen Associates, Inc.)

The project is expected to provide protection at a minimum beach design section for at least 6 years, based on an average annual bypass rate of 50,400 cu m/year (66,000 cu yd/year) at South Lake Worth Inlet. Placement of beach fill within the groin compartment did not begin until the T-groins were complete (April 1998), and the project was in place by April 1999.

Performance of the project over the initial 15-month monitoring period has been as designed. The beach within the T-groin field has maintained a stable beach cross section along the northernmost 610 m (2,000 ft) of shoreline, while allowing sand to migrate through the T-groin

field to the downdrift beaches. There is no evidence of downdrift erosion from the groins. The bypassing bar of the inlet attaches to the shoreline directly downdrift of the southernmost structure and nourishes the beach further to the south. Considering overfill losses, volumetric change during this period was predicted to be 68,800 m^3 (90,000 yd^3). Measured volumetric change was approximately 20 percent lower (53,000 m^3 or 70,000 yd^3).[1]

Creed and Olsen (1999) concluded presentation of the project with the following recommendations:

a. Mechanical sand bypassing should continue at the historical rate, but the discharge should be transferred south of the T-groin field. The T-groin field was expected to maintain a minimum beach berm, thereby requiring only occasional sand placement in this region.

b. Spurs should be added to the south jetty and northernmost groin. These elements were included in the original conceptual design, but were omitted because of absence of local participation. These elements are expected to further reduce the potential for sand losses from the T-groin region.

CONCLUSIONS: There appears to be general agreement that T-head and other composite groins can be effective in stabilizing beaches by holding the sand located directly on either side of the structures. At the same time, their potential for depriving downdrift beaches of sand and high initial (construction) cost is noted. Placement of composite structures is restricted to situations where they are economically feasible and their influence outside the direct project area is acceptable or can be acceptably mitigated.

Composite groins offer an effective solution to erosion along beaches located downdrift of inlets where there is a dominant direction of net transport and where the beach tends to be isolated from sediment supplies. Composite structures reduce losses, as well as prevent sand eroded from the beach from being transported to the navigation channel. Natural sand bypassing around the ebb shoal and periodic artificial nourishment, if necessary, can maintain the beaches further downdrift of the project.

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[1] Personal Communication, January 2001, Christopher Creed, Olsen Associates, Inc.

the CIRP Technical Leader, Dr. Kraus at the email address furnished or by telephone at (601) 634-2016. This CHETN should be cited as follows:

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